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Effect of soiling on photovoltaic modules in Norway

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Abstract

Accumulation of sediments, i.e. dust or dirt-particles may significantly reduce the output of a PV system. In Norway, the first significant installations in grid-connected PV appeared in 2014, and hence there is a growing interest in the performance of PV under Norwegian climate and insolation conditions. In this paper we study losses due to soiling of PV modules in an inland climate in Norway and assess the cleaning effect of rain in this environment. We also show that the effect of soiling can be accurately determined by a combination of optical measurements and high precision balance measurements, where the accumulated dust density is assessed by measuring the weight-changes of cloths used to clean glass samples. Initial optical and physical analysis of the dust at the field site must be performed in order to correlate the dust density to the reduction in transmittance for the soil present at the given site. After this correlation is established direct and quantitative measurements of transmission reduction due to soiling can be obtained for field locations without laboratory access. The weight measurements can hence supplement the classical method of applying a cleaned cell for reference to improve the accuracy of soiling studies performed for field deployed solar modules. This is of value for estimating power losses due to soiling for PV plants in remote areas, such as Kalkbult in South Africa.

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Keywords: soiling; PV; dust density; transmittance; anti-soiling coating

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1. Introduction

A substantial amount of research time and money has been invested to bring solar cells to their current STC efficiencies, while far less time and money have been invested in addressing externalities which prevents the solar cells from reaching similar conversion efficiencies when actually deployed in the field [1]. Accumulation of sediments, i.e. dust or dirt-particles, is one such external effect, which may significantly reduce the output of a PV system. Literature shows annual soiling losses ranging from between 1-7 % in regions such as Spain [2], [3], to more than 10% in dry locations such as Cyprus [4] and Kuwait [5]. Typically, areas with long periods without rain suffer more than areas with more regular rain events. The effect of soiling on field deployed PV modules is difficult to quantify because there are a very wide range of parameters, which affect the output of the solar cells. Both accurate prediction of power production and optimal cleaning solutions may depend on precise measurements of the production losses due to soiling. Accurate measurements are also needed to relate the amount of soiling on the PV panels to factors in the environment, and thereby get a better understanding of soiling losses and improve our capability of predicting them. The most widespread method used to assess the effect of dust on solar panels is to compare modules that are cleaned at regular intervals with otherwise identical modules that receive no cleaning [6], [7]. Some studies also use the solar irradiation as measured by a regularly cleaned pyranometer or determined from satellite data and compensate for the effect of temperature [4], [8]. These approaches give an estimate of the power lost due to soiling, but do not provide quantitative information about the amount of soiling responsible for this loss. A more fundamental understanding of power losses due to dust is provided through characterization of the optical, chemical and physical properties of the soil and the exposed glass samples [9]–[12]. These studies are usually performed using exposed glass pieces rather than full size framed modules, and at test sites in the immediate approximation of research laboratories. However, it would be beneficial to be able to carry out quantitative dust analysis also on modules in more remote field locations representative of many of the utility scale solar power plants. In this paper we describe quantitative measurements of dust and transmission losses at a test site in Norway, and how the approach used can supplement traditional soiling measurements and improve the accuracy of soiling studies performed at remote locations.

2. Experimental

2.1.Test site and laboratory in Norway

The test site in Norway is located in immediate proximity of an indoor optical laboratory. To study the natural accumulation of soil at the site, sixteen glass samples of standard low-iron 2 mm glass used in PV manufacturing are placed on the rooftop at a tilt angle of 45°. The glass has no microstructure, but eight of the glass samples had a commercial anti-soiling coating applied. The glass samples were mounted on a rack as an extension of an existing PV system using angle brackets for easy removal and remounting. The amount of soiling accumulated on the exposed glass samples is studied by use of a high precision balance with an accuracy of 0.0001 gram. The optical properties of the exposed glass are characterized using a dedicated setup for measuring angularly and spectrally dependent reflection and transmission measurements. Finally, the structure of the soiling material itself is characterized using Scanning Electron Microscopy (SEM).

2.2 Field test site in Kalkbult, South Africa

The field test site in SA is constructed within the fences of Scatec Solar’s 75 MW solar plant in Kalkbult. The area is semi-arid land with an annual rainfall of approximately 38 cm. There have been uncertainties related to the effect of soiling on PV modules in this type of climate. The modules deployed at the field test station are sixteen mc-Si modules from ReneSola and eight CdTe modules from FirstSolar. At the Kalkbult plant, Scatec Solar has 312 000 polycrystalline silicon modules from BYD. Data from the plant will allow for direct comparison of the energy output and reduce uncertainties. Each module at the field test station is connected to an active load to measure module temperature and full IV curves. The test site also includes dust traps and a weather station measuring direct and global irradiation, ambient temperature, wind, humidity, barometric pressure and rain.

2.3 Quantitative dust measurements

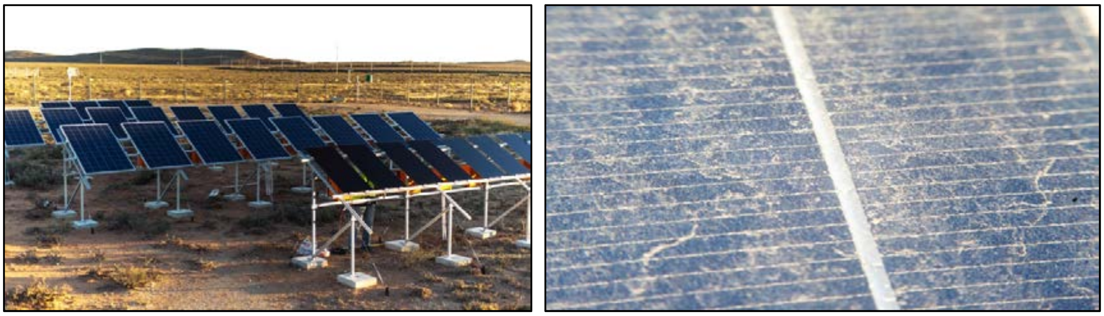

Fig. 1. (a) Test test site in Kalkbult, South Africa; (b) Example of soiling on one of the modules in the field.

In a study performed by [13], quantitative dust measurements were performed using small clean glass pieces with a precisely known surface area of 7x7 cm^2 to determine the average dust quantity that settled on each plate. After exposure, the glass piece was weighed using a digital precision balance. This approach could be transferable to more remote locations, but a high precision balance must be present at the site, and the use of a glass piece instead of a full size framed module is likely to influence the dust accumulation. An alluringly simplistic approach to quantify the amount of dust from a module would be to dry off the dust with laboratory cloths and subsequently weigh the cloths. Uncertainties associated with this approach include low accuracy due to small dust quantities, potential need of wetting agent to achieve satisfactory cleaning, and “loss” of dust during cleaning or transport of the cloths. To verify whether the approach provide a satisfactory level of accuracy, a series of measurements were performed where both the cloth and the glass samples were weighted before and after cleaning. Transmission and reflection measurements were performed before and after cleaning to correlate the quantitative amount of dust to reduction in transmission and changes in reflection, and to verify that the transmission was restored to expected values after cleaning. Measurements were performed both with dry cloths and cloths wetted with spirit or water.

3. Results and discussion

Combining the quantitative dust measurements and the optical characterization, an approximately linear correlation between the increase in soil density and the reduced transmittance is observed and shown in Figure 2. Based on the linear approximation we find that the transmittance is reduced by 0.09% and 0.11% per 10mg/m^2 for the normal and anti-soiling coated glass samples, respectively.

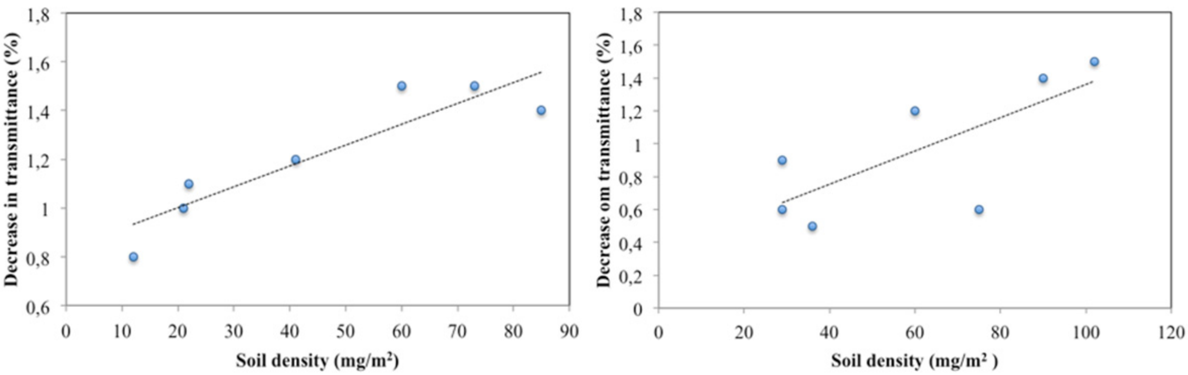

Fig. 2. (a) Measured decrease in transmittance as a function of soiling density for uncoated, non-textured module glass; (b) decrease in transmittance as a function of soiling for the same module glass coated with an anti-soiling coating. The dashed lines are linear trend lines, suggesting a linear relation between the reduced transmittance and soiling density.

Over the two-month period, the efficiency losses due to reduced transmittance after exposure in one week lie between 1 - 2% when weighted by the AM1.5 spectrum. Using the external quantum efficiency curve representative of a mc-Si solar cell, this loss in transmission corresponds to a loss in efficiency of 0.2-0.3 % absolute. Fig. 3 shows the dust density accumulated each week on normal and anti-soiling glass. The module glass with anti-soiling coating that is tested in fact accumulates more soil than the uncoated module glass. Also illustrated in Fig. 3 is the correlation between the measured dust densities and precipitation. As expected rain effectively clean the modules, however, even after heavy rainfalls, the efficiency of the cleaning seems to saturate at a dust density of approximately 40 mg/m^2. Such imperfect cleaning by rain showers was also indicated by [12].

The reduction in transmission per unit of soiling density is significantly less than what is found by Qasem [5] for higher dust densities, where a decrease of 2.8% for every 10 mg/m^2 is found. This illustrates the importance of initial optical and physical analysis of the dust present in order to correlate the dust density to the reduction in transmittance for the soil at the given site. After this correlation is established direct and quantitative measurements of transmission reduction due to soiling can be obtained for field locations without laboratory access, and contribute to improve the estimates of power losses due to soiling. Optical measurements were conducted to determine potential non-uniformity in the distribution of soil over the sample. No significant trends in the uniformity of the distribution could be detected. However, the glass samples used for these studies are much smaller than solar modules and lack the frame that is typically responsible for accumulation of soil towards the bottom of the module. Framed full size module glass will be installed at the test sites both in Norway and SA to provide more realistic information about the soiling distribution.

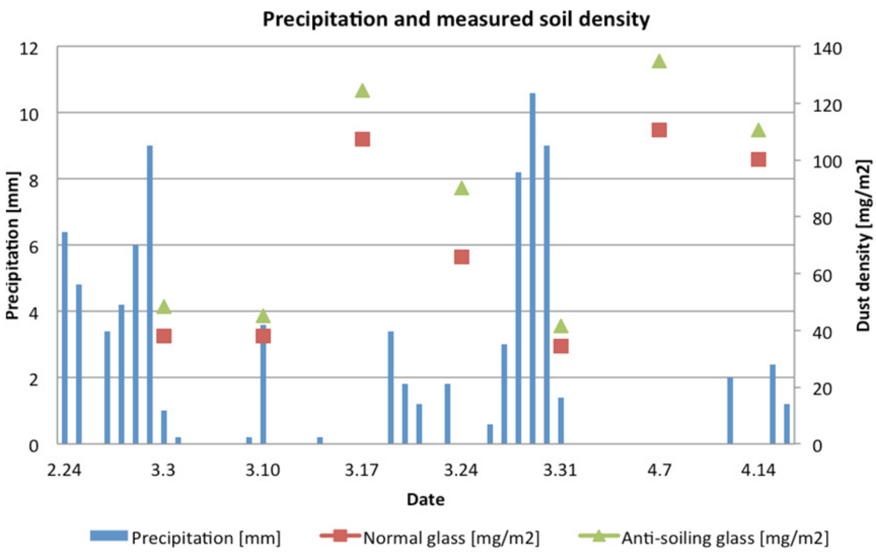

Fig. 3. Daily precipitation and accumulated soil density for module glass with and without anti-soiling coating.

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